

# Tree-rings to climate relationships in nineteen provenances of four black pines sub-species (*Pinus nigra* Arn.) growing in a common garden from Northwest Tunisia

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## ABSTRACT

In the Mediterranean region, the effects of climate change on tree growth have been more and more noticeable in recent decades. *Pinus nigra* is one of the most common mid-elevation pine in this region and one of the species most affected by increasing dryness. In Tunisia, in order to guide species selection for future reforestation of the Khroumirie Mountains, research studies are under way to improve knowledge of black pine ecology. The effects of interannual climate variations on radial growth were compared for 19 provenances of black pine in a 51-year-old common garden experiment in Souiniet (NW Tunisia, 492m) in a humid Mediterranean bioclimate. A significant positive correlation with April precipitation and a significant negative correlation with spring temperature were noted. A cool wet spring is beneficial to growth as it affects tree water balance at the onset of the growing season; in contrast, spring drought is responsible for low annual growth. Mild January–February temperatures have a positive influence on ring width as mild winters may foster photosynthesis and promote early resumption of cambial activity. Analysis of the pointer years showed that winter snow and hail are major factors limiting growth of black pine in the studied area. Despite overall similarities in ring width to climate relationships among provenances, differences observed attest to the interaction of the environment and genetic control of black pine diameter growth.

## 1. Introduction

In the Mediterranean basin, drought is the main constraint to plants (Specht, 1981). According to climatic models, a generalized rise in temperature and a decrease in precipitation, especially during the warm season, are expected well into the 21st century in the Mediterranean basin along with other extreme events (IPCC, 2013). This climate change will modify the growth, productivity and distribution of tree species in this area (Leal et al., 2008; Martín-Benito et al., 2010a,b; Martínez-Vilalta et al., 2008; Allen et al., 2010). In fact, the effects of climate change on forests will depend on how changes in water availability and temperature take place (Pichler and Oberhuber, 2007). Both negative and positive effects on forest growth have been observed. Summer and winter temperatures have opposite effects (negative and positive, respectively) on mean tree growth (Gea-Izquierdo et al., 2011;

Andreu et al., 2007) while the effect of precipitation before growth resumes in the spring may be greater than summer precipitation (Piovesan et al., 2008; Leal et al., 2008; Martínez-Vilalta et al., 2008; Martín-Benito et al., 2010a,b). In the Mediterranean basin, pine forests have been substantially affected by climate change in recent decades (Andreu et al., 2007; Leal et al., 2008; Martín-Benito et al., 2010a,b).

This study focuses on black pine which has shown recent evidence of sensitivity to climate change (Martín-Benito et al., 2010a,b). Black pine (*Pinus nigra* Arn.) is a circum-Mediterranean pine species whose natural range extends from Spain and North Africa to Austria, Turkey and Cyprus. Most forests can be found in mountain areas between 1000 and 1500 m a.s.l. Its populations are fragmented and exhibit high morphological, physiological, genetic and ecological variability (Barbéro et al., 1998; Giovannelli et al., 2017). Owing to this large albeit discontinuous range and its large genetic and phenotypic

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variability, black pine is regarded as a collective species (Isajev et al., 2004). Although there is no definite consensus on its taxonomy, six main subspecies are currently recognized: *P. nigra*, *salzmannii*, *dalmatica*, *pallasiana*, *laricio* and *mauretanica* (Quézel and Médail, 2003). Black pine has been drawing some attention among forest managers because it is assumed to be relatively drought resistant and able to adapt to various soil types and climate conditions (Quézel and Barbéro, 1988; Costa et al., 1997).

Black pine is useful for studying the effects of climate change on tree growth. Several studies have addressed the degree to which black pines are affected by climate change by means of climate-growth relationships (Strumia et al., 1997; Köse et al., 2012; Levanic et al., 2013; Shishkova and Panayotov, 2013). Dendroecology is the main scientific approach used to evaluate the influence of climate on the growth of a species. Tree rings can also be used to assess the influence of forest management and climate on tree growth, productivity and mortality (Fritts, 1976; Chen et al., 2010; Lapointe-Garant et al., 2010). Tree rings are very reliable indicators of forest health and decline (Dobbertin, 2005). However, a large amount of factors contribute to ring-width variations which must be removed by standardization procedures from ring-width series in order to isolate the influence of climate (Fritts, 1976).

In France, *P. nigra* ssp. *laricio* has been found to be a drought sensitive species, and climate change might induce forest growth decline in the future (Lebourgeois, 2000; Amodéi et al., 2013). In addition, the radial growth decline observed in the Western Mediterranean populations of black pine in Spain is consistent with increasing drought in the area, and in accordance with previous tree growth studies in dry-temperate regions (Martín-Benito et al., 2011). *P. nigra* has also been found to be drought sensitive: dry conditions before tree-ring formation are the major inhibitor of growth (Camarero et al., 2013). In eastern Iberia, it appears that climate change will compel decreasing radial growth because of increasing temperatures and decreasing precipitation (Macías et al., 2006; Piovesan et al., 2008). This trend of decreased radial increment has already been observed in some black pine populations from the Western Mediterranean basin (Martín-Benito et al., 2010a,b). There have been many dendroclimatic studies on *P. nigra* for the western and central parts of the species distribution area (Biondi, 1999; Strumia et al., 1997; Ritcher et al., 1991; Fuster, 2000; Leal et al., 2008; Andreu et al., 2008; Martín-Benito et al., 2008, 2010a,b). In Bulgaria, *P. nigra* ssp. *pallasiana* seems well adapted to high summer temperatures and can resist low winter temperatures (Yurukov, 2003).

Climate adaptation of trees involves both the genetic adaptation of populations and the ability of individuals to absorb environmental changes by modifying their phenotypical response (Mátyás, 1996). Adaptive capacities of forest trees to climatic change strongly depend on genetic diversity and geographic origins (Schaberg et al., 2008; Soto et al., 2010). Several studies have revealed an intraspecific variability in growth performance and different responses to climate, with the aim of selecting the provenances of *P. nigra* best adapted to the expected future climatic conditions. *P. nigra* is known for its relatively high individual and among-provenance and genetic diversity (Jagielska et al., 2007; Lucic et al., 2010; Seho et al., 2010; Giovannelli et al., 2017). Varelides et al (2001) showed differences in growth and significant site-provenance interactions of seventeen provenances of *P. nigra* from Greece, Turkey, Corsica and Calabria at three sites in northern Greece with different types of soils. In addition, according to Kreyling et al. (2012), cold hardiness of *P. nigra* differed between provenances, with provenances from colder regions showing a higher level of cold hardiness. Seedlings of six provenances of *P. nigra* exposed to drought and warming in a full factorial common garden experiment over two years showed that provenances of *P. nigra* differed strongly in their performance, while exhibiting a surprisingly uniform sensitivity to drought and mean temperature showing no sign of local adaptation (Thiel et al., 2012). Growth analyses of four provenances of European black pine growing on dry sites in southwest Germany (Austria, Bosnia, France

(Corsica), and Italy) revealed that the Corsican provenance differed from the three other provenances (Seho et al., 2010).

Adapting forest ecosystems to climate change is currently a major issue in forest management. Identifying suitable species or provenances is crucial when faced with environmental changes. In addition, insights into intraspecific variation in climate response are of paramount importance. In our study, we investigated intraspecific variation in climate response among black pine subspecies and provenances in a common garden located at the southern limit of its range. Provenance tests have the advantage of being able to compare different genotypes growing under similar climate conditions. From these tests, we were able to demonstrate the extent and distribution of genetic diversity in fitness-related traits of the tree species (Kremer et al., 2002; Savolainen et al., 2002). Few studies exploring interannual radial growth variations using common gardens have been conducted (Oleksyn et al., 1993; Savva et al., 2008, 2002; Seho et al., 2010). The objective of our study is to use a dendroecological approach to understand how different subspecies and provenances of black pine react to interannual climate variations in a common garden at Souiniet in the province of Ain Drahem (humid Mediterranean bioclimate). This type of study is necessary to understand which ecological factors drive ring-width variations within a species. Our aims were threefold: (1) to compare mean radial growth and mean sensitivity of nineteen provenances, (2) to further determine what are the climatic variables influencing radial growth of black pine, and (3) to compare radial growth response to climate variations for different sub-species and provenances.

## 2. Material and methods

### 2.1. Study site

The experimental site was the Souiniet common garden located in the Khroumirie region in NW Tunisia (36°48' N, 8°48' E, 492 m) (Fig. 1). It was established in 1966. The site is exposed to a humid Mediterranean bioclimate with temperate winters. The geological formations are dominated by Oligocene sandstones and varied clays. The soil is deep (180 cm) with an balanced texture (Argilo-silty -sandy soils) but poor in organic matter and chemical material.

### 2.2. Tree-ring sampling

The Souiniet black pine experimental site was installed on 26 December 1964. The experimental design was: 21 complete blocks (A to U) of 399 trees, each block contains 19 trees representing 19 provenances. Trees were spaced 3 m x 3 m apart.

The study focused on four subspecies of black pine (*salzmannii*, *laricio*, *pallasiana*, *nigra*) totaling nineteen provenances (Table 1). Two opposite cores were taken at breast height (1.30 cm) from 4 to 13 trees per provenance using an increment borer (Table 2). All cores were mounted on wooden supports and thoroughly polished with progressively finer sand paper.

### 2.3. Meteorological data

The monthly maximum and minimum temperatures and total precipitation data were collected from the Ain Drahem meteorological station (1969–2013) at an altitude of 676 m, approximately 10 km from the experimental site. The average annual precipitation was approximately 1534 mm/yr. The mean annual temperature was 15.6 °C, the hottest month being July (31 °C) and the coldest January (4.4 °C) (Fig. 1). In the study area, the dry period in summer lasts 3 months, from early June to the end of August.

### 2.4. Chronologies and climate-growth relationship analysis

Tree-ring width measurement at 0.01 mm accuracy was provided by

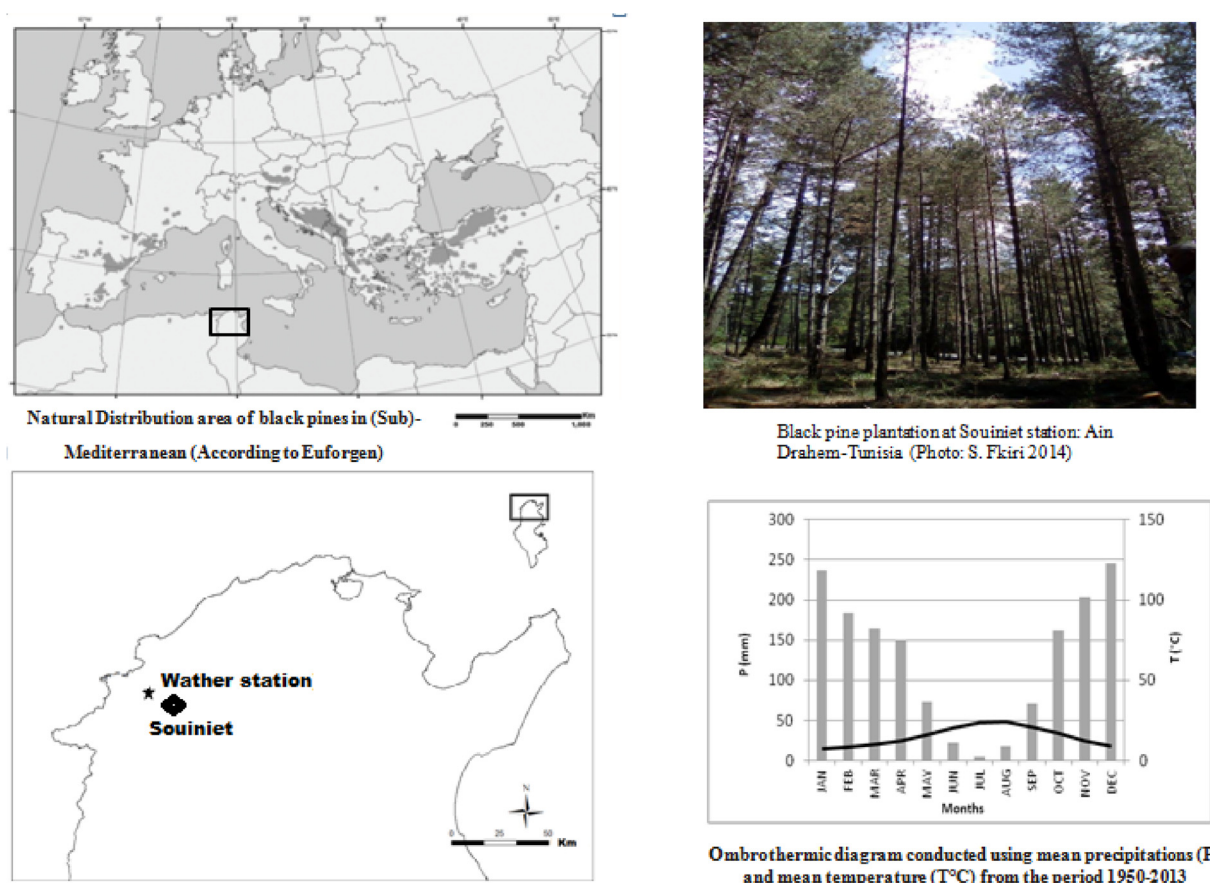


Fig. 1. Location of studied site.

the semi-automatic LINTAB system and WinTSAP (LinntabRinntech®). Ring width series were crossdated using the TSAPwin® program. Ring widths were measured and indexed with standard methods by removing low- and intermediate-frequency variations using a polynomial function (Lebourgeois, 2010). Crossdating and data quality were validated using the Arstan program and Dendrochronology Program Library in R (dplR) (Lebourgeois and Mérian, 2012).

Several statistics were calculated for the standardized chronologies. The mean sensitivity (MS) and first-order autocorrelation coefficient (AC) of the ring widths were calculated for each tree and averaged per

subspecies and provenance. MS is a measure of year-to-year variability whereas AC estimates the influence of the previous year's growth upon that of the current year (Fritts, 1976).

The mean interseries correlation (Rbar) assesses the coherence in growth among trees (Briffa and Cook, 1990). In addition, the expressed population signal (EPS) was calculated for site chronologies to verify the crossdating and robustness of the climate signal (Wigley et al., 1984).

Pointer years were calculated on the average ring-width chronologies in order to highlight the years in which radial growth was

**Table 1**  
Provenances List and geographic origin.

N°	Sub-species	Provenances	Country of origin	Altitude	Latitude	Longitude
P1	<i>Pinus nigra salzmanii</i>	Brougatles	France	–	44°07'35.4N	4°05'09"E
P2	<i>Pinus nigra calabrica</i>	Trenta Coste (Sila Greca)	Italie	1050	39°25N	16°35E
P3	<i>Pinus nigra calabrica</i>	Les Barres	France	150	47°50N	2°45E
P4	<i>Pinus nigra calabrica</i>	Cosenza	Italie	1300	39°15N	16°17E
P5	<i>Pinus nigra corsicana</i>	Bois frerot	France	100	–	–
P6	<i>Pinus nigra austriaca</i>	Puget Theniers	France	–	43°57'24.4N	6°53'53.0"E
P8	<i>Pinus nigra nigricana</i>	Kustentil	Bulgarie	900-1100	42°16N	22°41'49E
P9	<i>Pinus nigra pallasiana</i>	Alaçam	Turquie	800-1000	39°35N	28°35E
P10	<i>pinus nigra calabrica</i>	Catanzaro	Italie	–	38°54N	16°34E
P11	<i>Pinus nigra corsicana</i>	les Barres (leint)	France	150	47°50N	2°45E
P12	<i>Pinus nigra salzmanii</i>	Saint-Guilhem	France	350-400	43°41 N	3°35E
P13	<i>Pinus nigra pallasiana</i>	Crimée	Russie	500	44°33N	34°17E
P14	<i>Pinus nigra calabrica</i>	Grancia (Sila Greca)	Italie	850	39°41N	16°58E
P15	<i>Pinus nigra calabrica</i>	Aspromonto	Italie	1300	38°05N	16°00E
P16	<i>Pinus nigra salzmanii</i>	Cazorla	Espagne	1500	37°50N	3°00O
P17	<i>Pinus nigra calabrica</i>	Tavola (Sila Greca)	Italie	950	39°25N	16°35E
P18	<i>Pinus nigra salzmonni</i>	Olette	France	–	42°36'01.0"N	2°14'25.8"E
P19	<i>Pinus nigra calabrica</i>	les Barres	France	150	47°50N	2°45E
P20	<i>Pinus nigra corsicana</i>	Marghese	Corse	1100	41°39N	9°12E

**Table 2**

Number of sampling and Dendrochronological characteristics of the raw ring-width data for 19 provenance of black pine. Values were calculated using ARSTAN (Cook and Holmes, 1984) and Dendrochronology Program Library in R (Lebourgeois and Merian, 2012).

N°	Sub-species	Provenances	Number of cores	Number of trees	Age at 1.30 cm	RG (mm)	MS	(AR1)	Rbar	EPS
1	<i>Pinus nigra salzmanni</i>	Brougates	9	8	40	186.4a	0.247a	0.82a	0.318f	0.823dc
2	<i>Pinus nigra calabrica</i>	Trenta	12	8	42	194.2a	0.258a	0.81a	0.296d	0.834bcd
3	<i>Pinus nigra calabrica</i>	Les Barres	19	13	40	223.6a	0.252a	0.82a	0.420d	0.916ab
4	<i>Pinus nigra calabrica</i>	Cosenza	9	8	39	165.3ab	0.269a	0.83a	0.233 g	0.733ef
5	<i>Pinus nigra corsicana</i>	Bois frerot	20	10	40	171.5a	0.307a	0.81a	0.236 g	0.848bcd
6	<i>Pinus nigra austriaca</i>	Puget-Théniers	6	5	35	171.4ab	0.286a	0.83a	0.393 g	0.651 g
8	<i>Pinus nigra nigricana</i>	Kustendil	6	4	40	104b	0.28a	0.79a	0.040 h	0.020 h
9	<i>Pinus nigra pallasiana</i>	Alaçam	8	5	42	183.1a	0.268a	0.81a	0.317f	0.788de
10	<i>Pinus nigra calabrica</i>	Cantanzaro	5	5	41	184.9ab	0.245a	0.82a	0.484c	0.824dc
11	<i>Pinus nigra corsicana</i>	les Barres (leint)	14	8	41	198.5a	0.242a	0.79a	0.554b	0.554d
12	<i>Pinus nigra salzmaenni</i>	St Guilhem	8	8	40	169.9ab	0.232a	0.78a	0.449dc	0.867bcd
13	<i>Pinus nigra pallasiana</i>	Crimée	10	6	42	178.9a	0.251a	0.83a	0.286f	0.800de
14	<i>Pinus nigra calabrica</i>	Grancia	18	12	40	178.2a	0.291a	0.77a	0.490c	0.942a
15	<i>Pinus nigra calabrica</i>	Aspromonto	8	6	41	158.1ab	0.271a	0.76a	0.242 g	0.719f
16	<i>Pinus nigra salzmaenni</i>	Cazorla	7	7	41	203ab	0.264a	0.81a	0.364e	0.8de
17	<i>Pinus nigra calabrica</i>	Tavola	6	4	42	168.6a	0.299a	0.84a	0.292f	0.712f
18	<i>Pinus nigra salzmanni</i>	Olette	10	8	43	162.3ab	0.251a	0.81a	0.433d	0.884bc
19	<i>Pinus nigra calabrica</i>	les Barres	4	4	42	176.8a	0.277a	0.85a	0.677a	0.893abc
20	<i>Pinus nigra corsicana</i>	Marghese	18	10	42	179ab	0.247a	0.84a	0.758a	0.940a

Variables abbreviations are: MG Mean ring widths ( $p = 0.0004 < 0.05$ ), MS Mean Sensitivity is measure of year -to- year variability ( $p = 0.01 < 0.05$ ), AC first-order autocorrelation coefficient of ring widths ( $p = 0.396 > 0.05$ ), Rbar running mean inter-series Correlation ( $p = 0.0001 < 0.05$ ), EPS expressed population signal ( $p = 0.0001 < 0.05$ ).

Values with the same letter are not statistically different.

particularly high or low.

For the purposes of statistical analysis and model fitting, we used the SAS® statistical program. For analyses of variance, multiple comparisons of means, we used the generalized linear model (GLM) of SAS. The multiple comparison of means was done by using the Newman-Keuls method threshold risk 5% (means with the same letters are not significantly different).

The relationship between climate and ring widths was investigated using bootstrapped response functions and the program 3pBase (Guiot and Gœury, 1996). Bootstrapped response functions were calculated using 24 monthly climatic parameters (mean monthly temperatures and total monthly precipitation from October of the previous year to September of the current year) as regressors and the master index chronology as the dependent variable. The bootstrap process method consists of calculating the regression on years drawn by lots. For each iteration, the regression coefficients and the multiple correlation of climatic regressors are computed on the years randomly selected (calibration years). An independent verification is carried out on the observations omitted from the subsample (verification years). The response function consists of the mean values and standard deviation of partial regression and correlation coefficients between actual values and values reconstructed from climate. The significance of each bootstrapped regression coefficient is provided by the ratio between the mean value calculated from the results of the simulations and its standard deviation. When the ratio equals 1.96, the significance of the regression coefficients attains 95% probability (Lebourgeois, 2000).

### 3. Results

#### 3.1. Chronology statistics

Tree-ring series of individual trees showed an age-dependent trend similar among the studied provenances. The juvenile growth stage clearly exhibited a higher growth in provenance Tavola of sub-species laricio (Fig. 2).

Comparing interannual variations of the mean curves of the 19 provenances showed good agreement in negative and positive peaks, confirmed by a high degree of common variance throughout several periods (Fig. 3).

The analysis of variance showed significant differences between the

mean ring widths of the 19 provenances of black pine. According to the Newman and Keuls test, there were three distinct groups, the lower group including Kustendil from the subspecies nigricans, which had the lowest ring width. Kustendil showed the highest expressed population signal (EPS, Table 2). The EPS was below the critical value of 0.85 proposed by Wigley et al. (1984). Rbar and EPS were negatively correlated to the number of cores measured. Mean sensitivity varied between 0.23 for Saint Guilhem (salzmanii) and 0.31 for Bois Frerot (subsp laricio) which expressed the highest high-frequency (year to year) variance. The first-order autocorrelation coefficient was above 0.7 in all provenances, emphasizing the high interannual correlation between ring widths (Table 2).

#### 3.2. Pointer years

The period from 1975 to 1986 was characterized by a high number of negative pointer years. From 1986, wide and narrow rings were noted alternately. In 1981, 1982, 1983 and 1993 more than 60% of provenances showed a negative pointer year. 2004 was the only year in which more than 60% of provenances had a positive pointer year (Fig. 4).

Positive years were characterized by low amounts of annual precipitation and high temperatures (12 mm and 21 °C in 2004) for the two months (September and October) when black pine cones mature, compared to negative years (64 mm and 19 °C in 1993) (Fig. 5). The negative pointer years were characterized by winter snow and hail compared to positive years (Table 3).

#### 3.3. Climate-radial growth relationship

Radial growth of black pine was positively affected by April precipitation and negatively correlated with May precipitation. Ring width was positively correlated with low January-February temperatures and negatively correlated with low spring temperatures (May-June).

Three provenances, Brougates (P1), Cazorla (P16) and Olette (P18) of subspecies salzmanni, Alaçam (P9) of subspecies pallasiana and Les Barres (P3) of subspecies laricio var. corsicana, were positively correlated to April precipitation (Fig. 6). Provenances P1 (Brougates), P3 (Les Barres), P6 (Puget-Théniers) and P9 (Alaçam) were negatively correlated with May precipitation. Only three provenances of



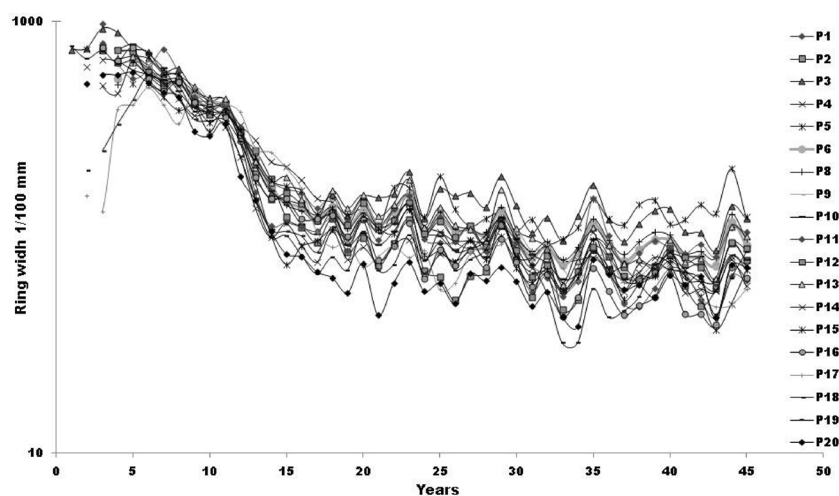


Fig. 2. Ring width chronologies for 4 black pine Sub-species planted in 1964 in the northwest of Tunisia.

subspecies *salzmanni* (P1, P16 and P18) and two provenances of subspecies *laricio* (P3 and P11) were negatively correlated with July precipitation (Fig. 6).

Low winter temperatures (January–February) were positively correlated with growth for eight provenances: four provenances of subspecies *salzmanni* (Brougatles (P1), St Guilhem (P12), Cazorla (P16) and Olette (P18), and four of subspecies *laricio* (Les Barres (P3), Grancia (P14), Aspromonto (P15) and Les Barres (leint) (P11)). All these provenances were negatively correlated with low temperatures at the end of spring (May–June) (Fig. 6).

The radial growth of provenances Brougatles and Cazorla of

subspecies *salzmanni* was negatively correlated with high temperatures in May and June (Fig. 6).

#### 4. Discussion

Black pine is a species with very high edaphic and climatic amplitude and is found on very different soils and bioclimates (Isajev et al., 2004). In fact, different provenances are adapted to different soil types from podzolic sands to limestone (Papaioannou, 2015): Corsican, Italian and Sicilian origins grow poorly on limestone (Sevgi and Akkemik, 2007) where pine requires deep soils. Conversely, Turkish and Crimean

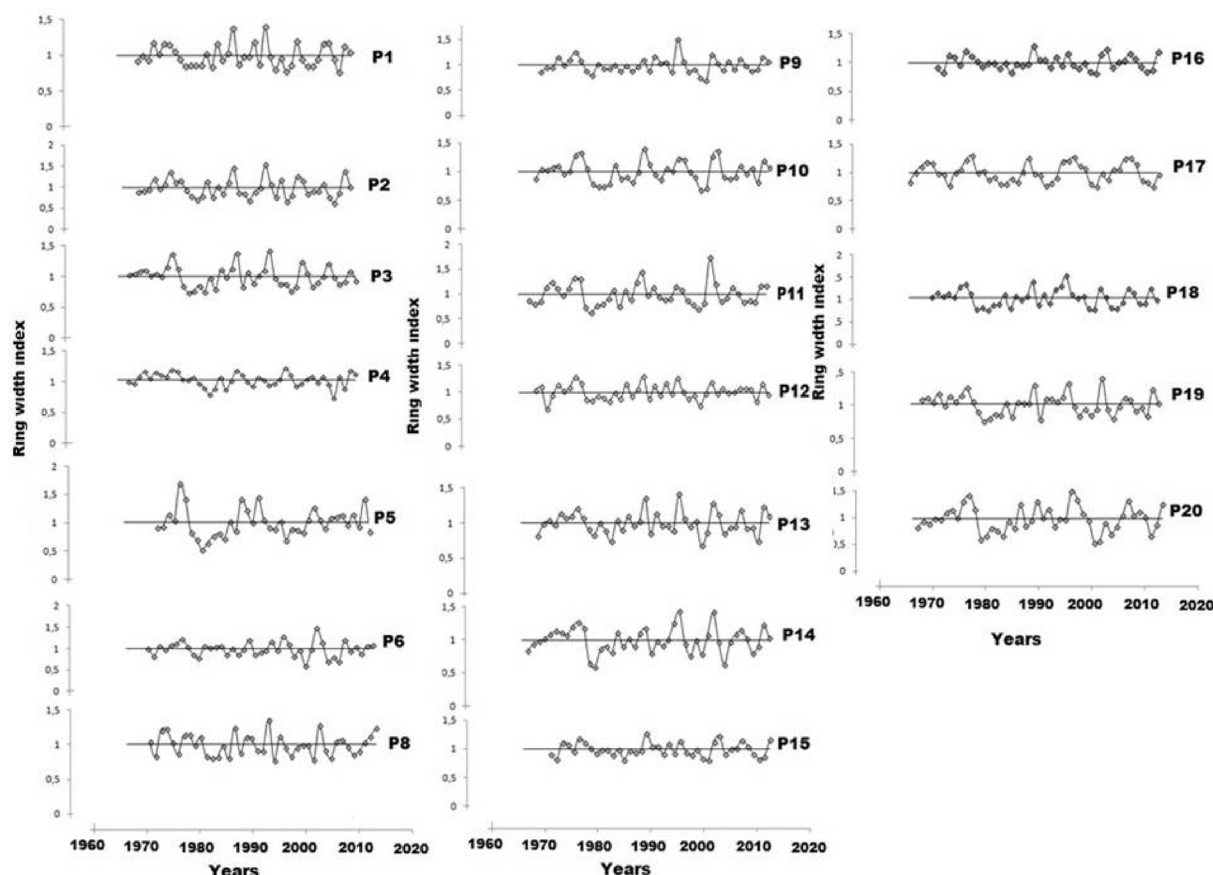


Fig. 3. Ring width index chronologies averaged across 19 provenances of *Pinus nigra* species planted in 1964 in the northeast of Tunisia.

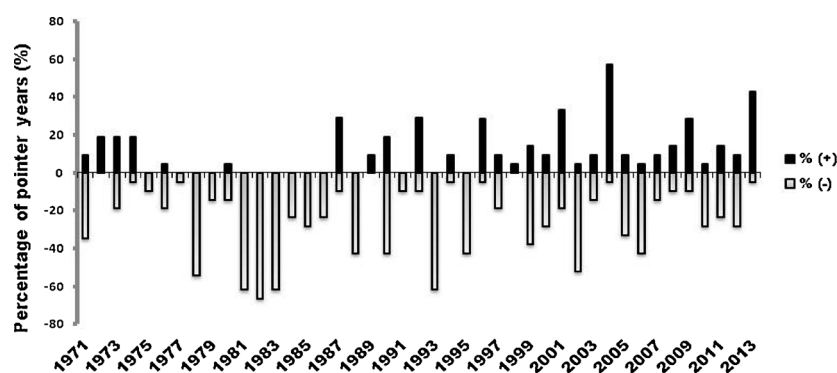


Fig. 4. Percentage of pointer years for period 1971–2013 from 19 provenances of black pine.

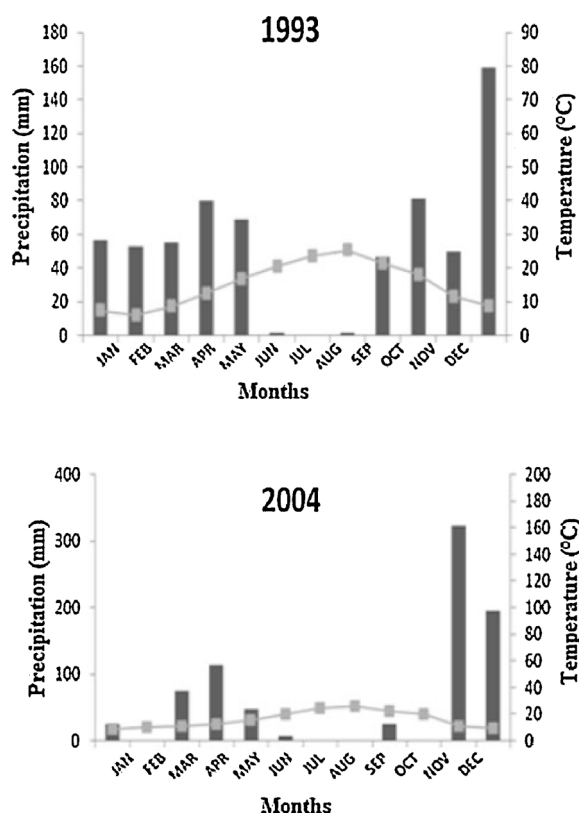


Fig. 5. Ombrothermic diagrams from the average precipitation (mm) and temperature (°C) from the period of negative (1993) and positive (2004) characteristics.

Table 3

Snow and Hail winter.

Years	Months		
	December	January	February
1981	*S	**S	
1982	**S	**S	
1983		*S	*S
1991			***S
1993		*S	*****H
1994	**S + *****H		
2001			****H
2002	*****S		
2003		*S	*****H

S: Snow; H: Hail; \*: Number of day.

origins grow well on limestone. *P. nigra* subsp. *pallasiana* can be cultivated on both siliceous and calcareous soils. *P. nigra* subsp. *salzmanni* grows on calcareous soils better than *P. nigra* subsp. *nigra* which grows well on siliceous terrain. Austrian and Pyrenean provenances grow well on a wide range of soil types. The Albanian black pine usually prefers dolomites and serpentine soils (Dida et al., 2001).

In our study, we assessed radial growth to climate relationships in several black pine provenances growing in the same environment at the southern limit of the species' distribution range. April precipitation appears as the main critical environmental factor for radial growth of several black pine provenances. Positive correlations with April precipitation could be interpreted as a limiting effect of water deficit in April, a critical level of water supply triggering severe decrease in radial growth. Lebourgeois (1998) showed that rainfall deficits during the growing season lead to significant growth reduction of the two varieties of *P. nigra* subsp. *laricio* (corsicana and calabrica). In addition, Amodei et al. (2013) showed that Salzmann pine is sensitive to water deficit in spring. Other studies have pointed out that black pine is sensitive to high summer temperatures and water deficit in spring and summer (Martín-Benito et al., 2010a,b; Lebourgeois, 2000; Génova and Fernández, 1999).

An insufficient water balance under high temperature conditions is responsible for low annual growth (Martín-Benito et al., 2008). We found a negative relationship with May precipitation for some provenances of black pine, confirming results obtained in the central Apennines (Italy) (Alma et al., 2014). Excessive rainfall in May and June may hamper cell wall thickening and therefore ring width. May and June temperatures are negatively correlated with ring width. Indeed, soil dryness caused by high evapotranspiration may lead to smaller needle formation which not only reduces water loss, but also the amount of photosynthates available for growth (Oberhuber et al., 1998). Negative relations with high May, June and July temperatures and Salzmann pine radial growth have been mentioned by other authors (Isajev et al., 2004; Amodei et al., 2013).

The positive relationship observed between radial growth and high January and February temperatures may reflect the beneficial effect of high temperatures on the resumption of cambial activity (Creber and Chaloner, 1990). High temperatures in winter make dormancy stimulate hormone secretion causing earlier cambial activation, thus increasing the length of the growing season (Bogino and Bravo, 2008).

Precipitation during the previous autumn has a positive effect on growth of the following year, whereas high temperature has a negative effect. Black pine shows greater sensitivity to high temperatures during the previous autumn (Martín-Benito et al., 2013) as a result of their influence on carbohydrate accumulation and cambial zone formation (Martín-Benito et al., 2010a,b; Andreu et al., 2007; Vaganov et al., 2006).

In Mediterranean climates, cold winter temperatures and summer drought limit tree growth as trees face double stress. It snows almost every year from December to February in Souiniet, and particularly in

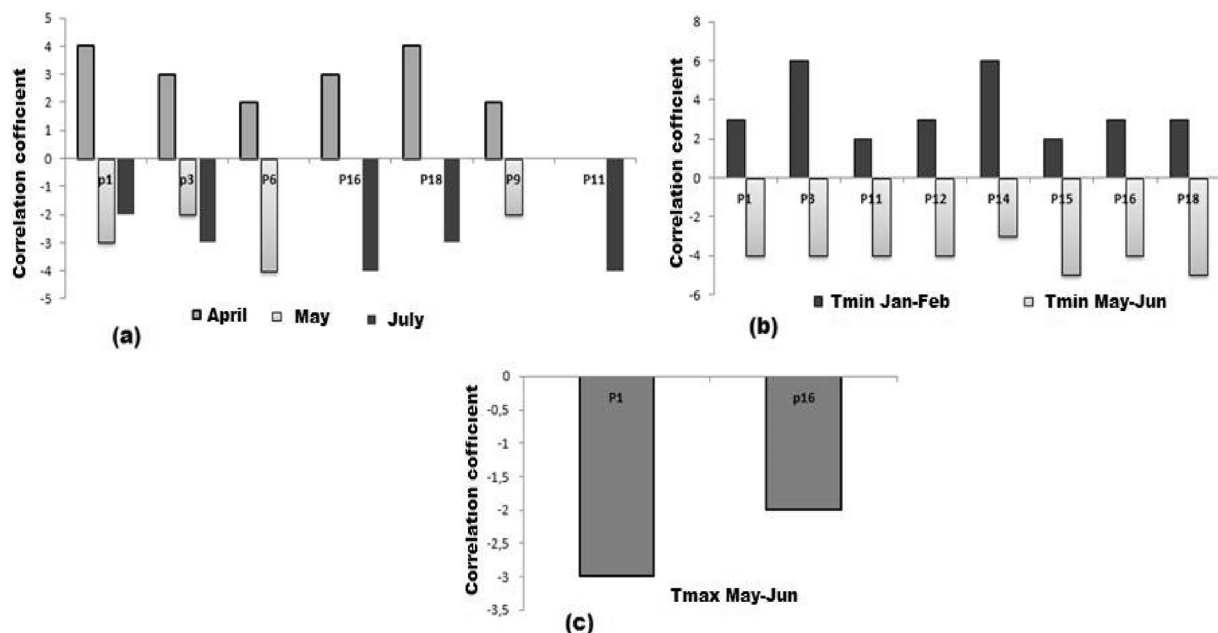


Fig. 6. Response function of *Pinus nigra* ring-width to: (a) Precipitation from April, May and July (b) to monthly minimal temperature (Tmin) from January -February and May-June (c) to monthly maximal temperature (Tmax) from May-June.

January and February (Poupon, 1974). Although no snow damage has been reported since the installation of the Souiniet common garden, our study shows negative pointer years are sometimes characterized by snow and hail.

Tracing between-provenance variation probably represents the most powerful tool available for testing hypotheses of climatic adaptation in trees. Most of these studies are based on an analysis of the environmental and genetic control of height and diameter growth of provenances (Mátyás et al., 1997). Our results show similar patterns in ring width to climate relationships for different provenances. However, out of nineteen provenances, eight do not show any significant relationship with climatic variables. Therefore, despite similarities in ring width to climate relationships, differences occur among provenances which attest to the interaction of the environment and genetic controls of diameter growth.

## 5. Conclusion

Spring water deficit seems to be the main constraint exerted on black pine radial growth in Northwest Tunisia. In addition, low temperature and high temperatures effects on radial growth are significant in January/February and May/June respectively for some subspecies and provenances. The balance between positive and negative effects of spring water availability and winter/spring temperatures on radial growth may determine the future performance of the provenances planted at Souiniet. Our results also reveal slight differences between provenances which could be attributable to genetic and genetic x environment effects. This should be further investigated in other common gardens submitted to other bioclimates. Future efforts should also include ecophysiological studies to better evaluate the *P. nigra* provenances that might be more adapted to the expected future average climatic conditions.

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